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*TITLE: A MODAL SURVEY OF THE M1A1 MAIN WEAPON SYSTEM

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*ABSTRACT:

When a tank fires its main weapon system, a complex chain of dynamic events begins. The projectile is accelerated down an imperfect gun tube (gun tubes are never perfectly straight) being forced by the burning propellant gases. During this time, considerable forces and interactions between the projectile and gun tube are possible. In some cases, the response of the two systems (i.e., the projectile and gun tube) are not fully understood. One method of examining the dynamics of these complicated chain of events is to develop straightforward numerical models. As a first step in assuring the accuracy of these models, verification of the assumptions, such as geometry and boundary conditions, must be examined.

This paper discusses an experimental modal survey of the M1A1 main weapon system. Both horizontal and vertical components are examined to find the actual frequencies and mode shapes of the system. A simple numerical model is developed using the finite element method and subsequently compared to the experimental results of the modal survey. A discussion of the system's attributes, as well as the techniques and assumptions used to develop the finite element model are discussed at length. Possible shortcomings in the numerical approximation are outlined as well.

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OBJECTIVE

The primary purpose of this modal test was to provide experimental verification for a finite element (FE) model of the M1A1 tank M256 main gun. The FE model is being developed for the gun accuracy improvement program. Major vertical and horizontal rigid body and bending modes of the main gun will be obtained from experimental modal analysis (EMA). The realism of the FE boundary conditions (between the main gun and its supporting structures) may be enhanced by comparison to the EMA model. The secondary objectives of this experiment included measuring the nonlinearity of the gun modal responses and determining, if any, the effects of the hydraulic gun elevation mechanism on the gun dynamics.

TEST SETUP

All of the heat shields on the gun were removed and the accelerometers were attached directly to the gun tube. The accelerometer locations were situated in two lines, 90° apart. This positioning permits one set of vertical data and one set of horizontal measurements to be obtained. In order to resolve the fifth bending mode, 15 locations, 10 inches apart, were chosen from the muzzle to the king nut. Only four locations, due to inaccessibility, were measured within the turret. Table 1 and Figure 1 detail the placement of the measurement locations. The chosen excitation locations were at the muzzle (location 200) and in the king-nut area (location 100). Both vertical and horizontal excitation was utilized. The excitation source was a 50-lb electrodynamic shaker. To ensure uniform energy distribution over the frequency range of interest, a controlled true random signal was utilized as the excitation signal.

SIGNAL PROCESSING

A 16-channel Genrad 2515 spectrum analyzer was utilized to acquire the measurements. Since more than 16 measurement channels were utilized, 2 runs were required for each configuration. Frequency response functions (FRFs) and coherence functions were retained in the final data set. In addition, several auto spectra were also retained to evaluate the excitation signal. The FRFs were collected with the following parameters:

Maximum Frequency	640 Hz
Frame Size	2560 Frequency
Frequency	0.25 Hz
Number of	50
Window Type	Hanning

FRFs collected to assess nonlinearity of the structure utilized a higher frequency resolution in order to detect small frequency shifts.

FINITE ELEMENT MODEL DESCRIPTION

The M256 120-mm gun system consists of a number of important parts which contribute to the system's dynamic characteristics. Figure 2 is a cut-a-way, three-dimensional view showing some of the parts in the cradle assembly area. This figure, as well as the model, do not consider the mantelet or trunnion mounts. This is discussed in the conclusion section of this paper. The objective of this first FE model, namely, a beam element representation of the system, was to make a simple, easily modified, numerical model of the M256 gun-recoil system. Then this simple model will be used as a learning tool for more sophisticated FE models in the future. The complicated set of boundary conditions in the system is first examined with the simplistic model. That model is then compared with experiments and improved based on observed discrepancies. Model attributes are incrementally changed until a satisfactory numerical representation of the M256's dynamic characteristics is made. The characteristics (realistic geometric and boundary conditions) of the simple model are then incorporated into more sophisticated and robust three-dimensional FE models which are not so quickly modified or analyzed.

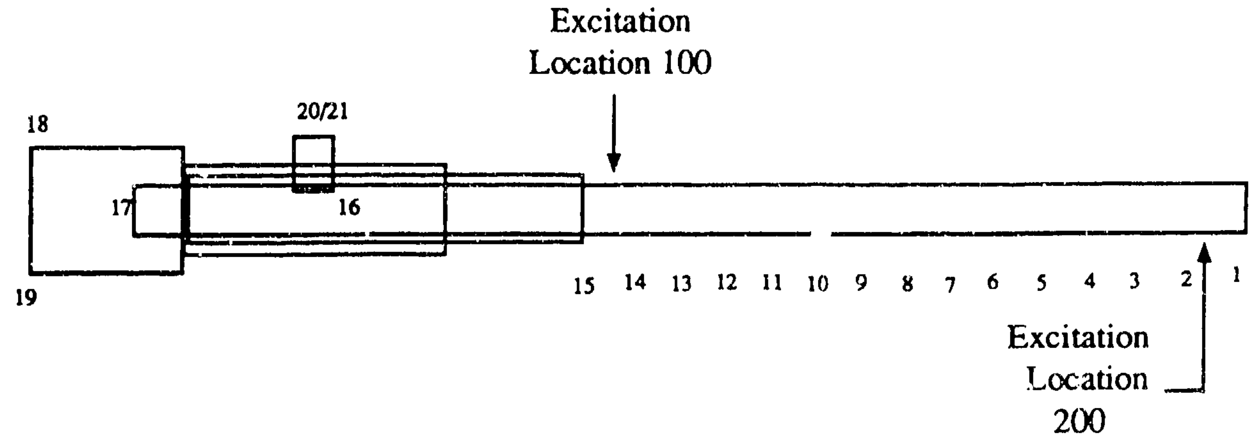


Figure 1. Measurement Location Diagram.

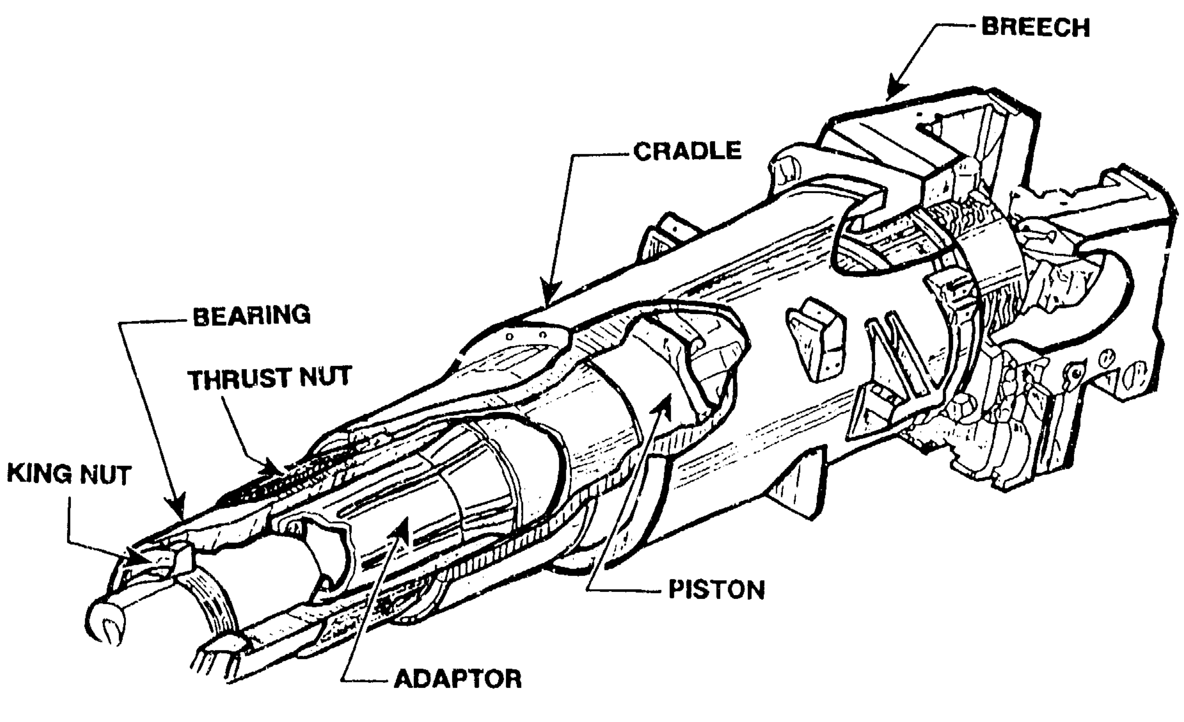


Figure 2. Cut-a-Way View of the M256 Assembly.

Table 1. Measurement Location Dimension

Location No.	Distance From Muzzle	Description of Gauge Location
1	.05	@ Muzzle
2	10.	On Gun Tube
3	20.	On Gun Tube
4	30.	On Gun Tube
5	40.	On Gun Tube
6	50.	On Gun Tube
7	60.	On Gun Tube
8	70.	On Gun Tube
9	80.	On Gun Tube
10	90.	On Gun Tube
11	100.	On Gun Tube
12	110.	On Gun Tube
13	120.	On Gun Tube
14	130.	On Gun Tube
15	135.	On Gun Tube
16	180.	On Cradle
17	208.7	On RF of Gun Tube
18	218.	On Breech
19	218.	On Breech
20	~191.	On Elev. Mechanism
21	~191.	On Elev. Mechanism

After examining the mechanical drawings of the system and then examining its associated parts, as well as its assembly and disassembly, a simplified model of the M256 consisting of what is believed to be critical components was developed. The critical components were combined into nine individual parts. These nine essential parts are highlighted in Figure 2. Additionally, Figure 3 shows a computer aided design/computer aided manufacture (CAD/CAM) drawing of the simplified parts which are going to be included in the FE model. For the beam element model, each of the parts is represented using concentric cylindrical beam elements with associated properties to the pieces shown in Figure 3. However, the adapted bearing, king-nut, and thrust nut were included in the beam element model of the piston. The piston was assumed to be rigidly attached, as was the breech, to the gun tube at the contact points. Similarly, the cradle, which supports the structure, was modeled, at first, with rigid contact points where the piston rested on the cradle's surfaces (Wilkerson et al. 1993). Initially, it was understood that this would be insufficient for modeling the recoil system's motion. Nonetheless, it was assumed that this would be sufficient for finding the first five vertical flexural frequencies and associated mode shapes correctly. Due to clearances between the piston and cradle in the real system, that was not the case. In particular, the contact

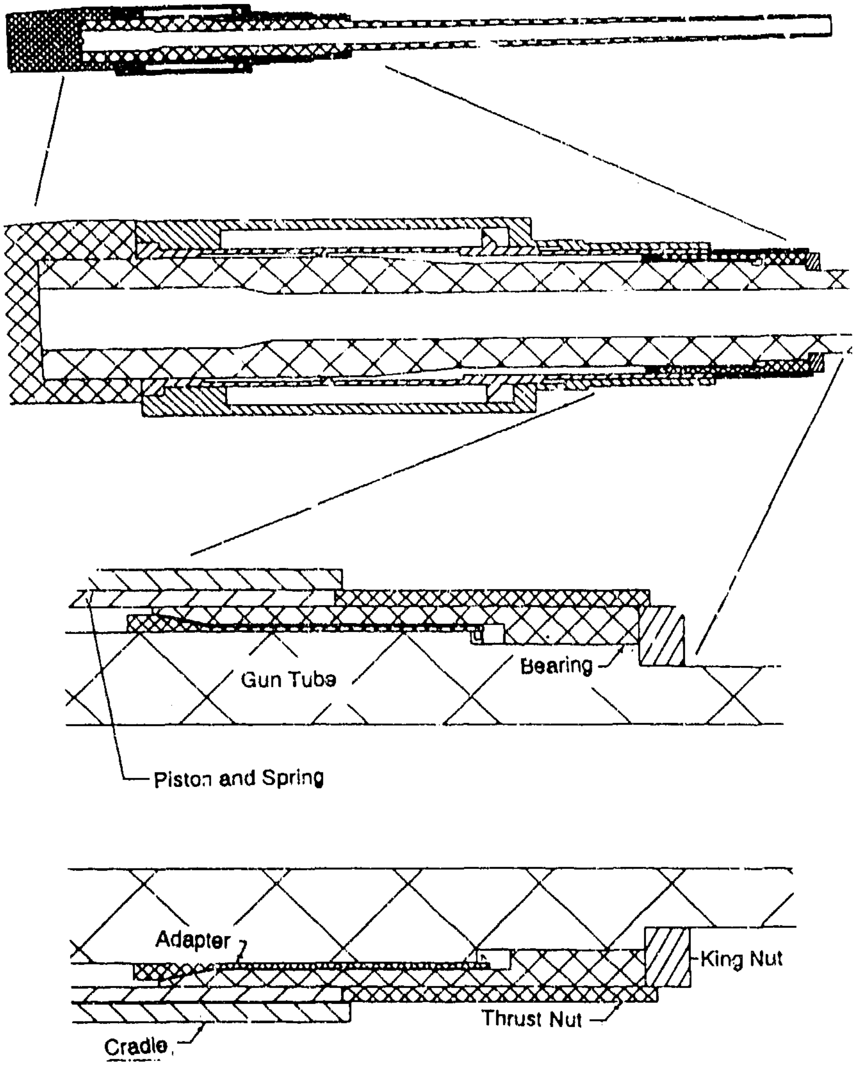


Figure 3. CAD/CAM Simplification of M256 Critical Components.

points, where the piston slides inside the cradle, required more flexibility than the rigid connections allowed. Subsequently, the rigid connections were replaced by gap elements. These gap elements gave the system more flexibility and better approximated the actual systems dynamic characteristics. (Note: gap elements are simulated with regard to the vertical modal analysis as spring-dashpots, but act as gap elements allowing the system to recoil.) The final model consisted of the gun tube, breech, piston, and cradle assembly. The cradle was simply supported at the same location as the trunnions. The elevating mechanism was approximated in the model as a spring-dashpot which attached between the cradle assembly and a rigid mount.

In order to check the FE model's geometric properties, it was assembled incrementally. First, the model of just the gun tube was compared with some experimental results of the free-free vibrational frequencies of that part (Rowekamp 1987). This was a good initial check of the model's most important part, namely, the gun tube. Afterwards, the breech, piston, and cradle assemblies were included in the model. Results comparing experimental frequencies to the numerical model's predictions are given in Table 2 and Figure 4 for the gun tube alone. A comparison of the experimental and numerical model for the assembled M256's frequencies and mode shapes are given in the results section of this paper.

Table 2. Gun Tube Only - Free-Free

Mode Shape	Experimental Results	Beam Model		3-D Model	
		Freq.	Error	Freq.	Error
1	37.5	36.4	3.0	35.6	5.3
2	106.3	106.1	0.2	104.5	1.75
3	211.3	214.4	1.5	210.6	0.34
4	337.0	394.3	3.6	336.5	0.15
5	482.5	510.3	5.8	488.6	1.3

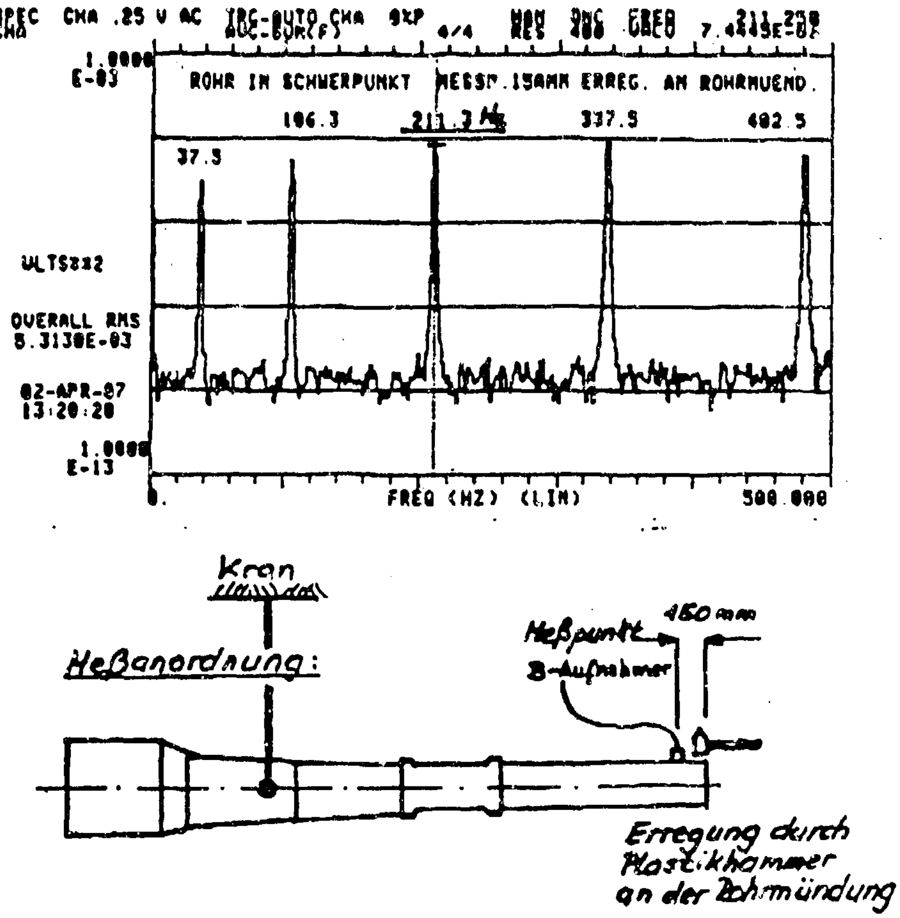


Figure 4. Frequency Response Function for Gun-Tube in Free-Free Mode.

RESULTS

The natural frequencies found in the experimental analysis for vertical and horizontal flexural components are summarized in Tables 3 and 4. Table 3 also summarizes the numerical predictions from the model in the vertical direction. No numerical predictions have been made for the horizontal flexural components. The mode indicator functions for frequency ranges 0–200 Hz and 200–640 Hz are given in Figures 5 and 6 for the vertical and Figures 7 and 8 for the horizontal, respectively.

Table 3. Vertical Modal Parameters

Mode Label	Flexural Mode	Damping % of Critical	Magnitude in Driving Point, FRF	Frequency		Error (%)
				Exp.	Calc.	
1	---	2.724	11.24	11.6	10.5	11
2	1	1.096	20.02	30.27	31.4	3.8
3	2	4.074	4.78	79.5	85.7	7.8
4	3	1.127	4.37	182.	178.9	1.7
5	4	1.143	4.66	276.	287.9	4.0
6	4	2.355	11.9	376.	366.	2.8
7	5	2.392	1.37	495.	455.	8.8

Table 4. Horizontal Modal Parameters

Mode Label	Damping % of Critical	Magnitude in Driving Point FRF	Frequency (Hz)
1	1.33	25.65	16.57
2	2.17	2.36	40.85
3	4.74	4.96	73.8
4	2.33	1.88	134.6
5	2.49	2.56	170.5
6	4.69	1.70	240.0
7	3.91	.925	332.4
8	.512	1.24	342.0
9	2.53	3.24	479.4

A small nonlinearity study was performed on the M256 cannon. This study was performed in only the vertical configuration with the excitation force at the king nut. Data was collected at six excitation levels (1 lb, 4 lb, 6.2 lb, 8 lb, 10 lb, 12.5 lb) from 0 Hz to 320 Hz at seven locations. The first two modes were quite linear. Modes 3 (80 Hz) and 4 (182 Hz) manifested some interesting effects (Figure 9). Both of these modes showed two lower amplitude peaks preceding the frequency from which the modal parameters were extracted. In the nonlinearity study, these initial peaks showed a large variation in amplitude and frequency compared to the third (primary) peak. This observation is a good indicator that the system can exhibit nonlinear behavior, particularly in certain frequency ranges. No attempt was made to simulate this behavior with the numerical model. Further, it is very likely that the two peaks observed are primarily the result of boundary conditions (interfaces between tube and piston, or piston and cradle) and not the dynamic properties of the M256 tube itself.

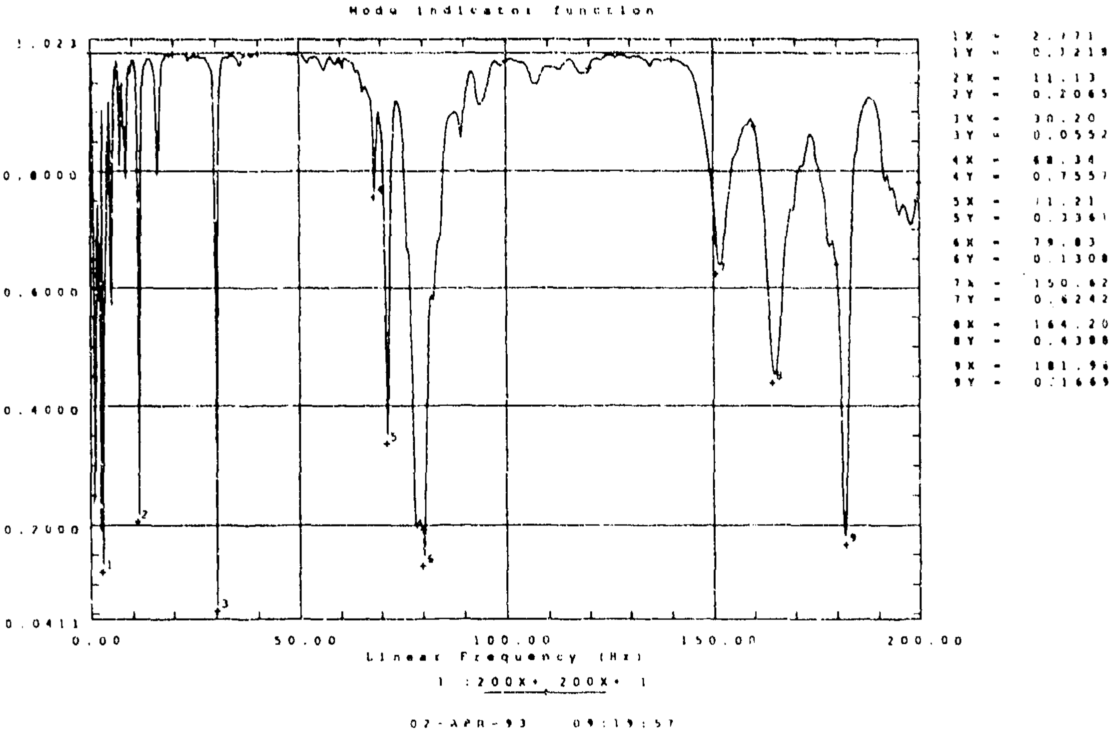


Figure 5. Mode indicator function for vertical frequencies out to 200 Hz.

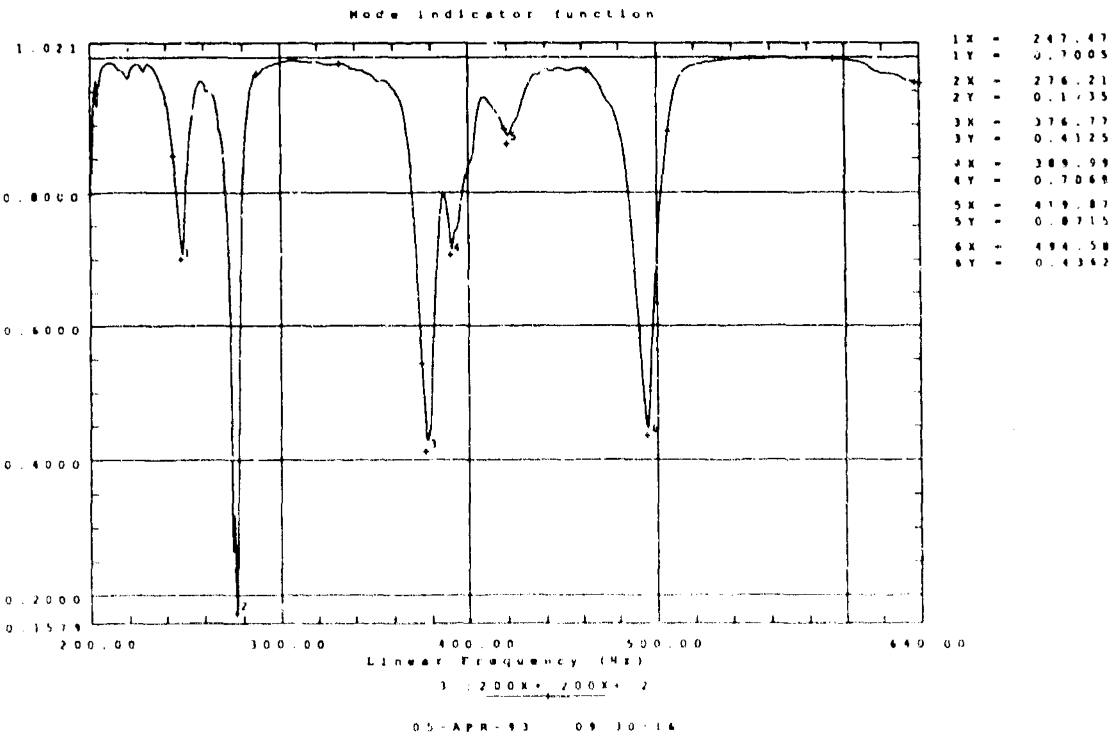


Figure 6. Mode indicator function for vertical frequencies from 200 to 640 Hz.

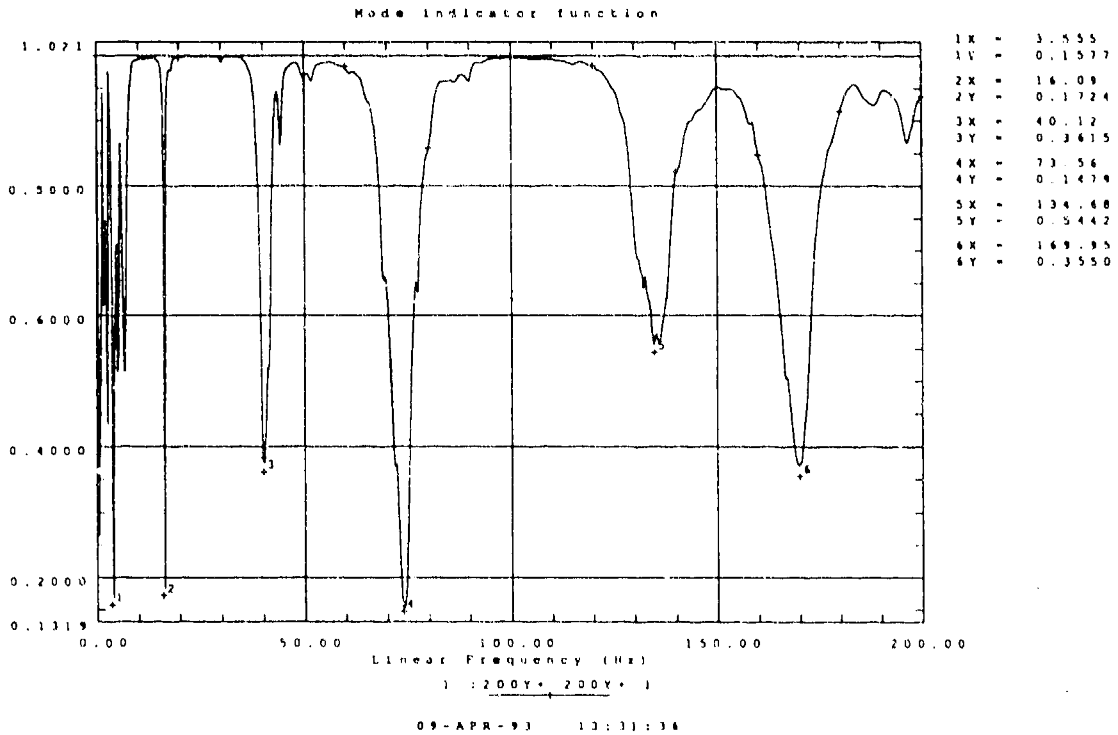


Figure 7. Mode indicator function for horizontal frequencies out to 200 Hz.

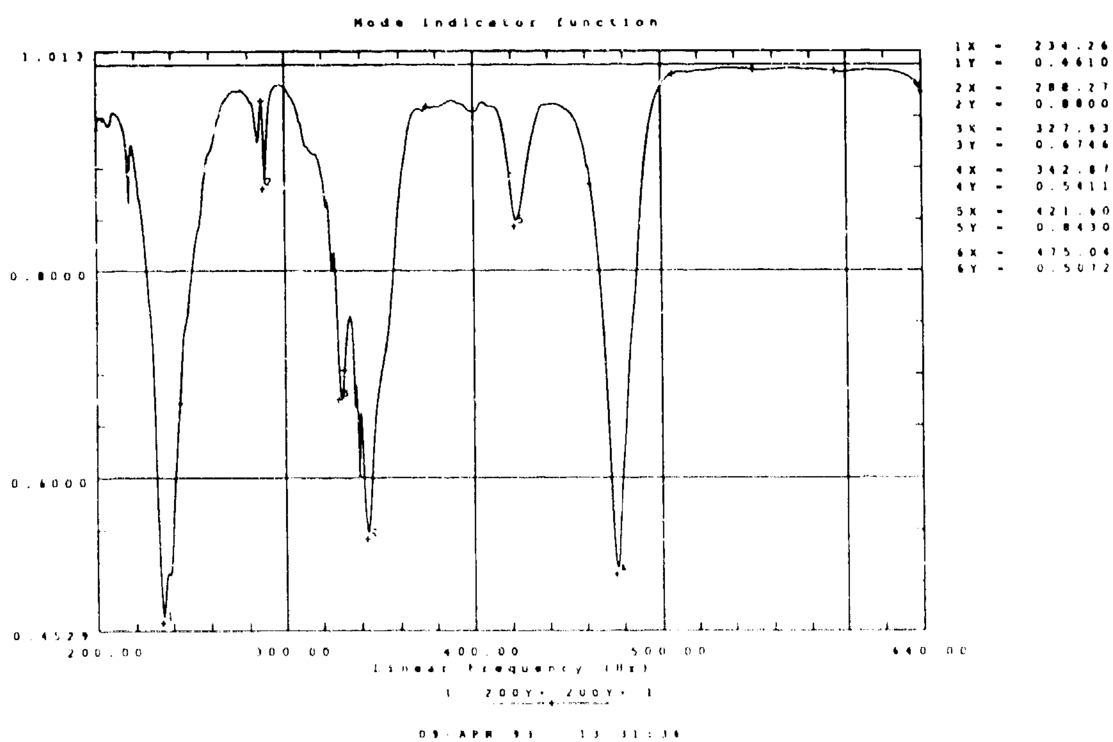


Figure 8. Mode indicator function for horizontal frequencies from 200 to 640 Hz.

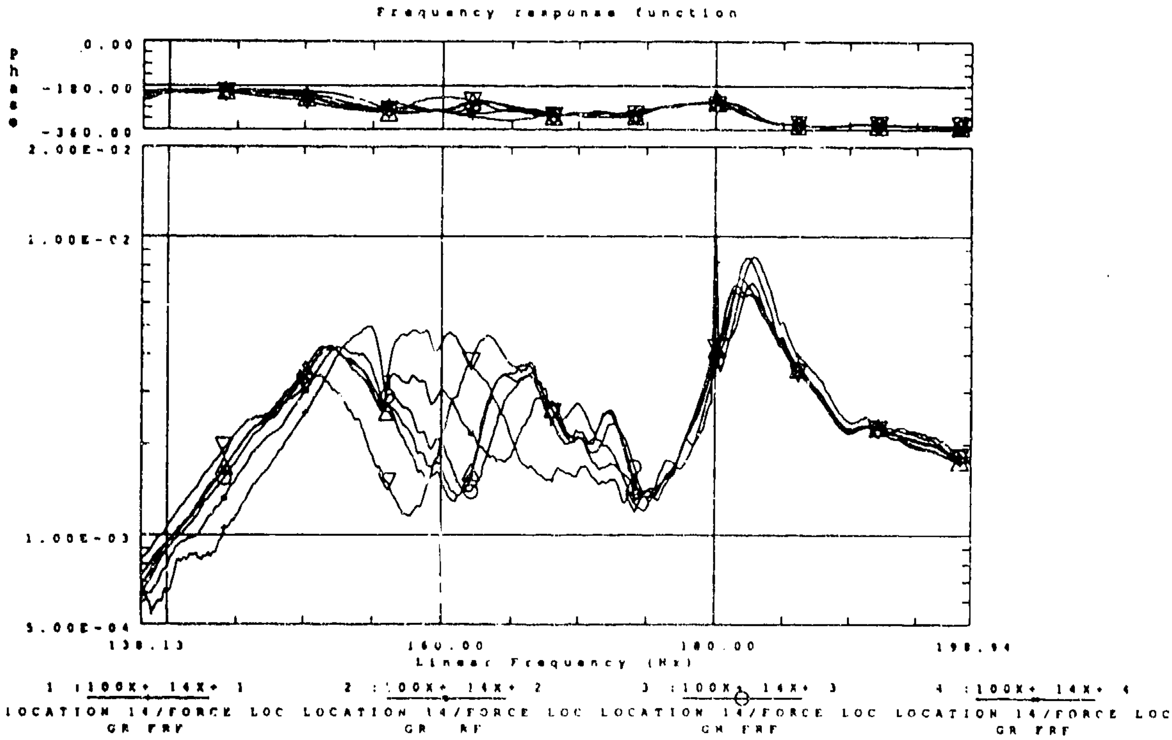


Figure 9. Nonlinear study, mode indicator function for 0 to 320 Hz.

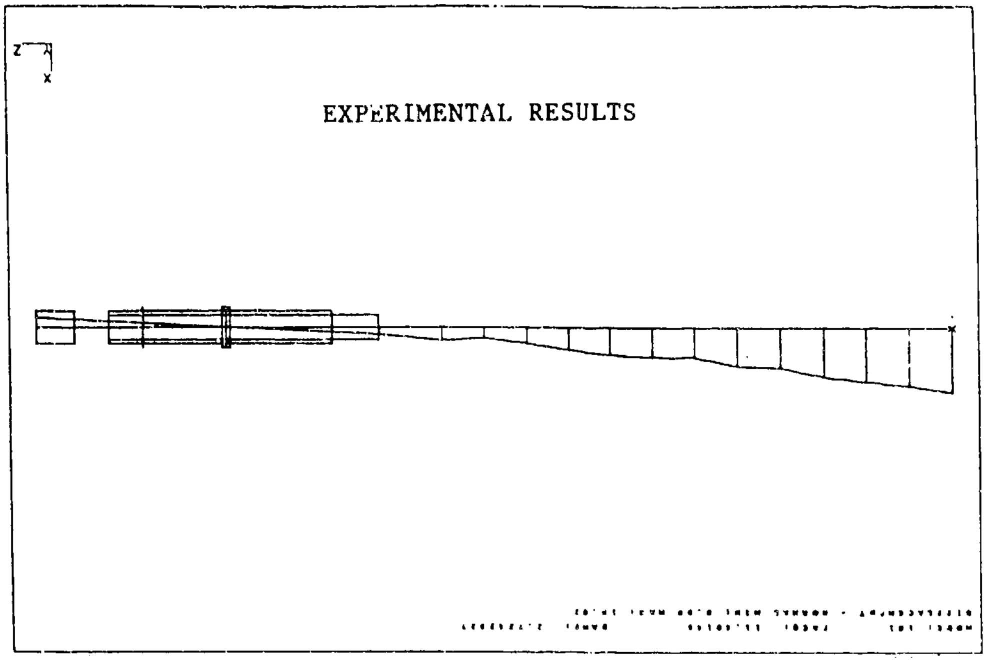
Figures 10–16 show the numerical and experimental mode shapes for each of the first seven major frequencies obtained. As can be seen in the figures, the early mode shapes (i.e., rigid body mode and the first two flexural frequencies) compare with the numerical predictions quite well. However, due to insufficient accessibility in the cradle region of the M256, the shapes of flexural modes 3–5 are not completely resolved in the experiment. Consequently, the actual assumed shape is penciled into the experimental figures based on the estimations made by the numerical model.

CONCLUSIONS

The confidence in the accuracy of the modal parameters for the first five modes of the vertical configuration and the first four modes of the horizontal configuration is high. There is significantly less confidence in the accuracy of the damping and frequency values for the higher order modes. In the vertical configuration, several modes appear in the mode indicator function and frequency response functions which were not extracted in the modal analysis. These modes have mode shapes which are extremely similar to mode shapes which were extracted. It is believed that these extraneous modes result from complex boundary conditions and are not present in the dynamics of the tube itself, but only the system as a whole (tube, plus its supporting structure).

The current FE model shows reasonable agreement with the experimental results. However, the experimental mode shapes for flexural modes 4 and 5 must be resolved to determine if the numerical predictions are correct and to verify that there are multiple flexural mode 4 shapes. This can only be done by increasing the number of sensors on the gun tube inside of the cradle. This could have been accomplished by attaching the sensors to the inside of the gun tube; however, it was not thought of at the time of the test.

There was also a fair amount of difficulty in numerically predicting both the first rigid body mode and the first flexural mode. Both modes are dependent on the spring constant used to simulate the elevating mechanism. A stiffer spring constant makes it easier to duplicate the rigid body frequency while making the first flexural mode too stiff. Therefore, it was



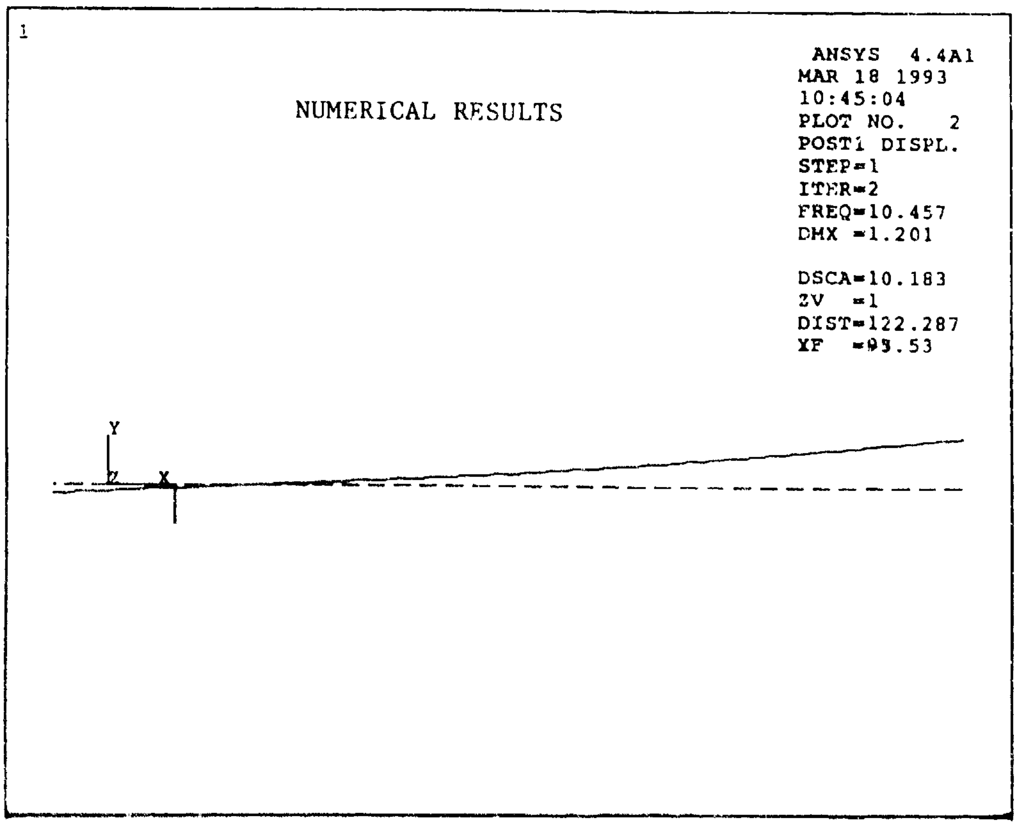


Figure 10. Comparison of numerical and experimental vertical mode shapes (rigid body mode).

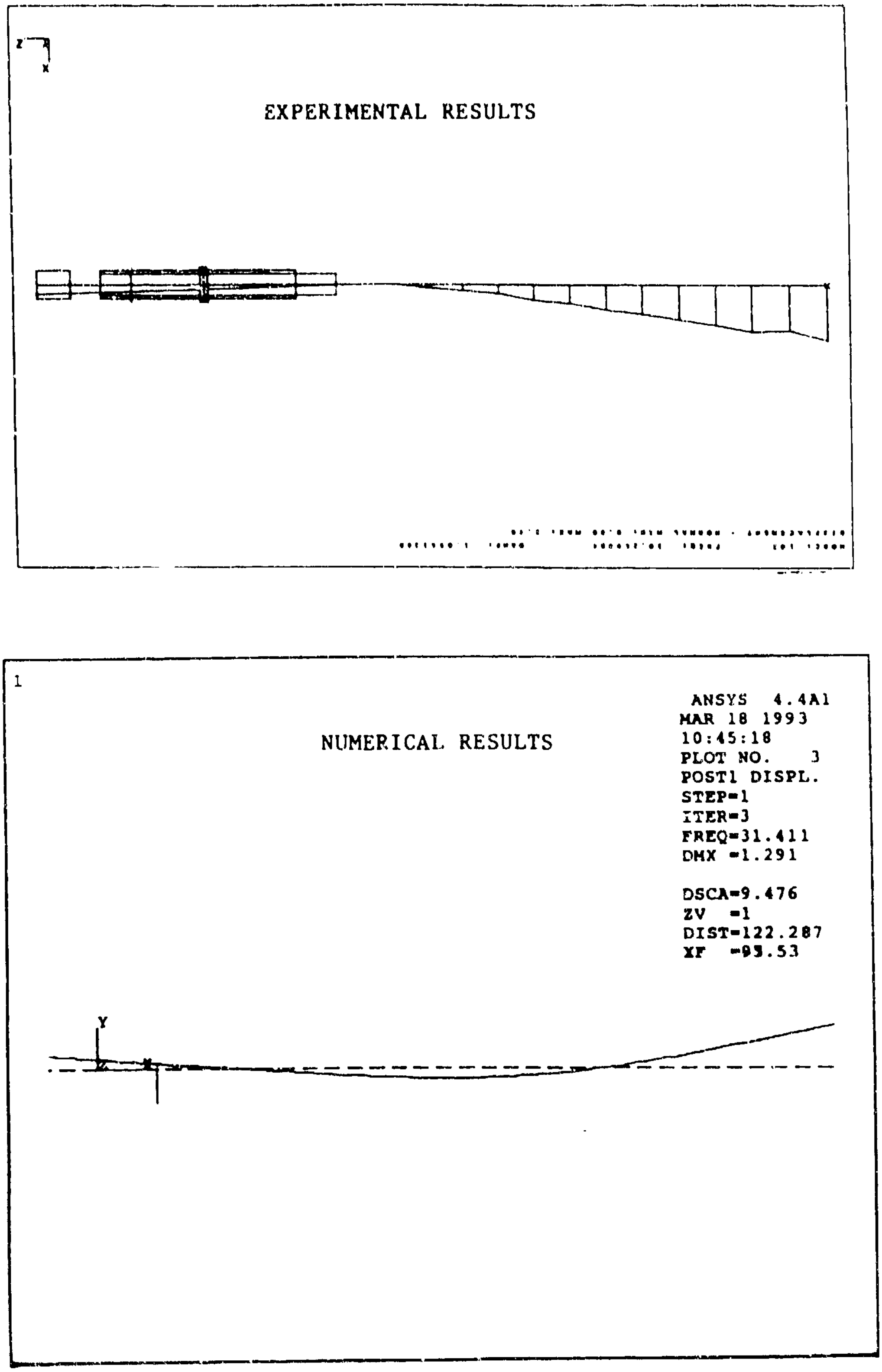
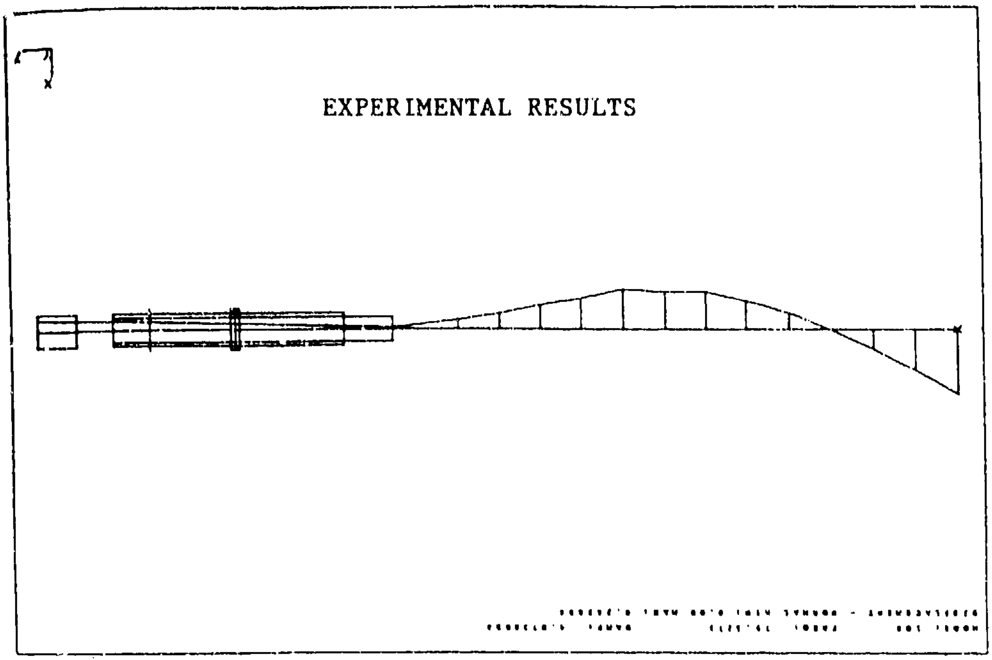


Figure 11. Comparison of numerical and experimental vertical mode shapes (first flexural mode).



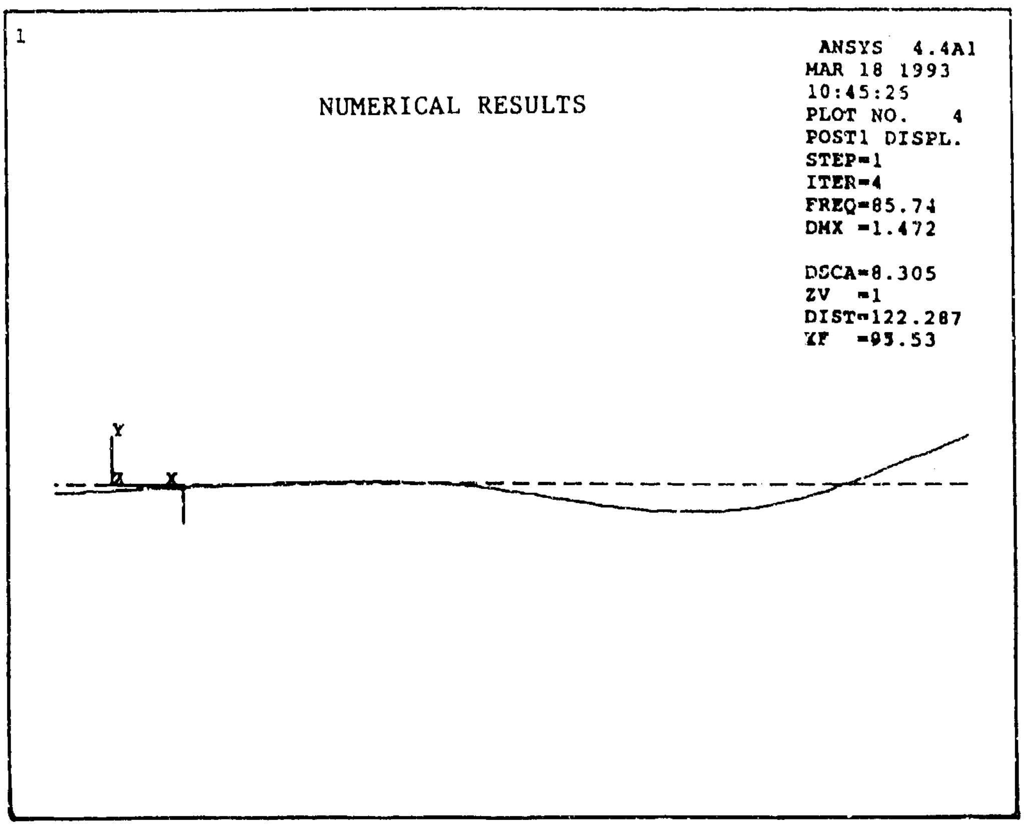
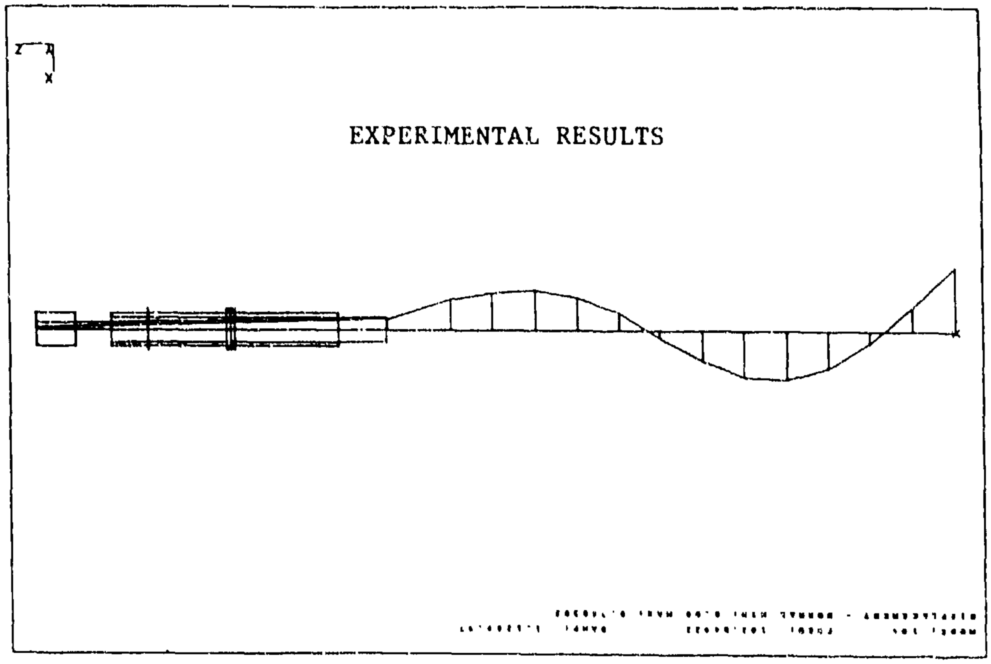


Figure 12. Comparison of numerical and experimental vertical mode shapes (second flexural mode).



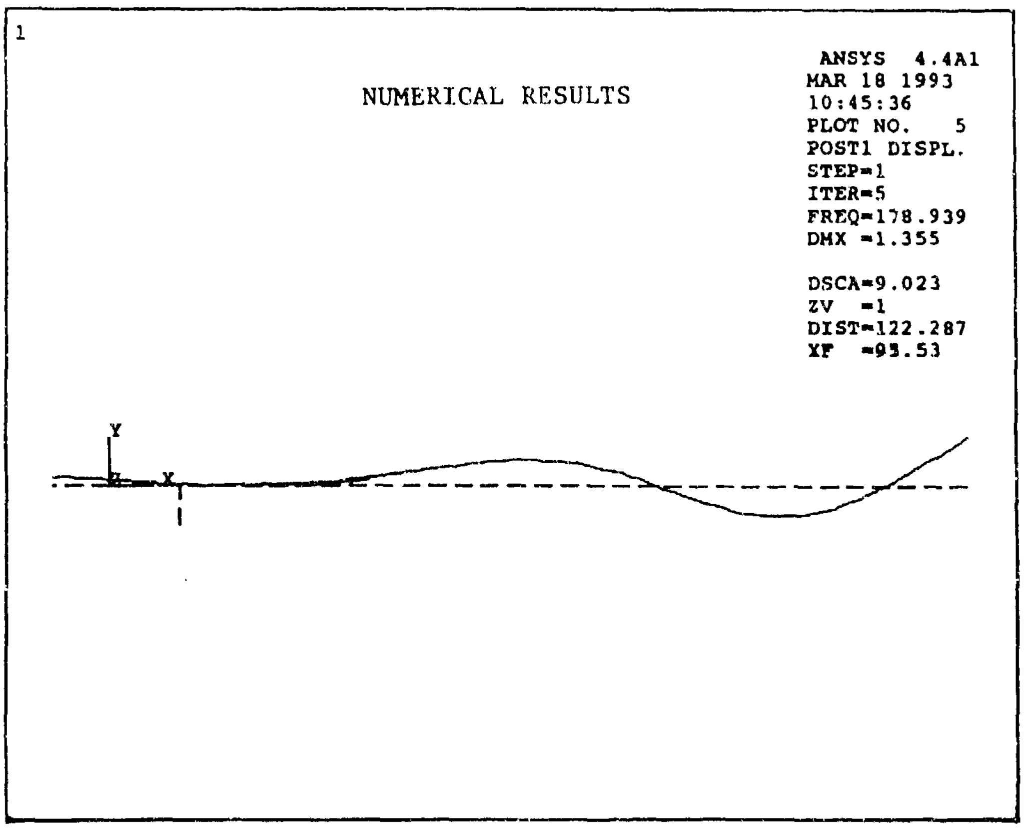
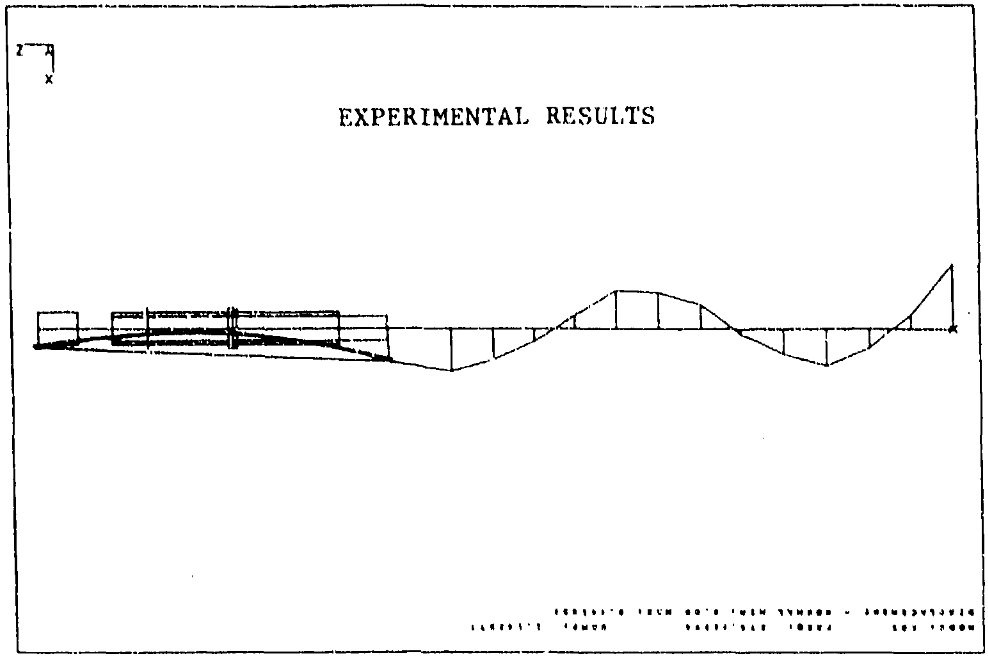


Figure 13. Comparison of numerical and experimental vertical mode shapes (third flexural mode).



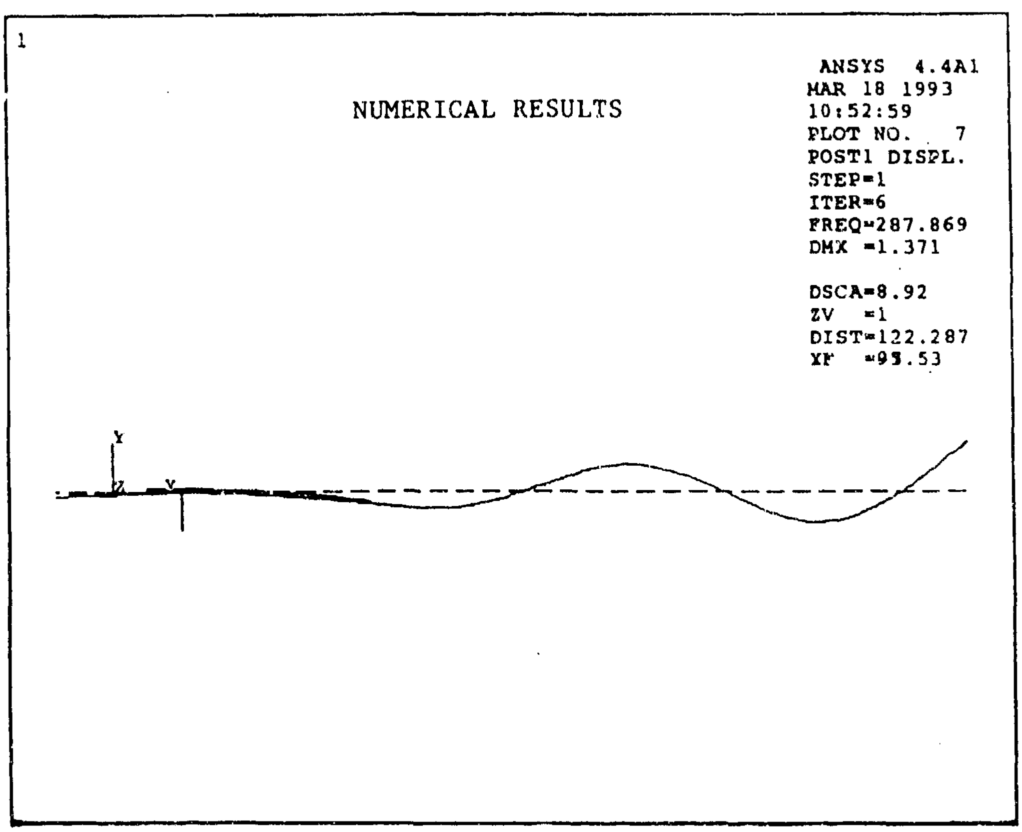
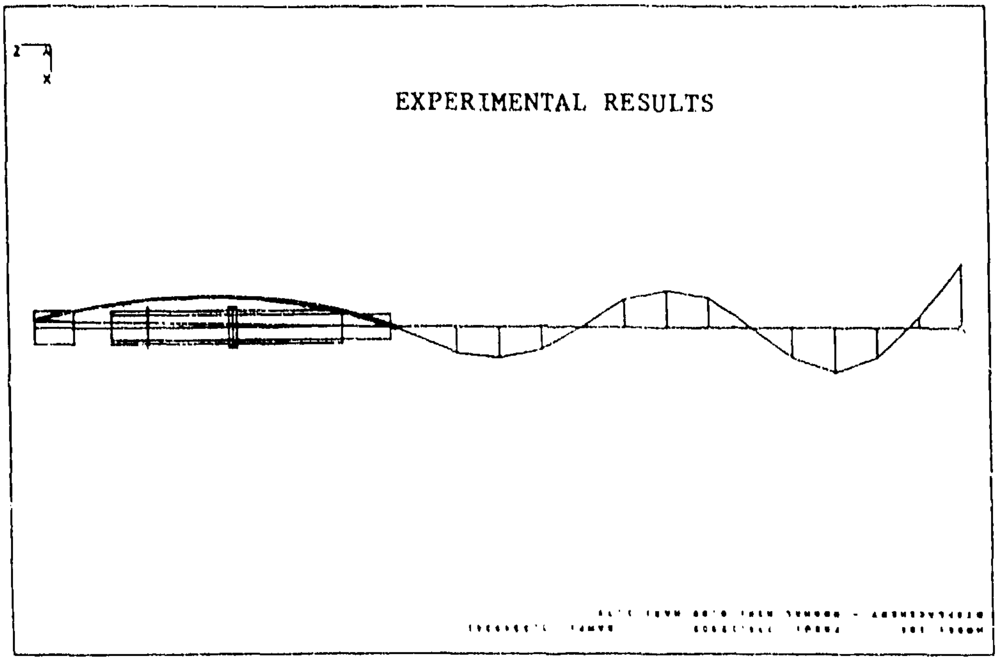


Figure 14. Comparison of numerical and experimental vertical mode shapes (fourth flexural mode).



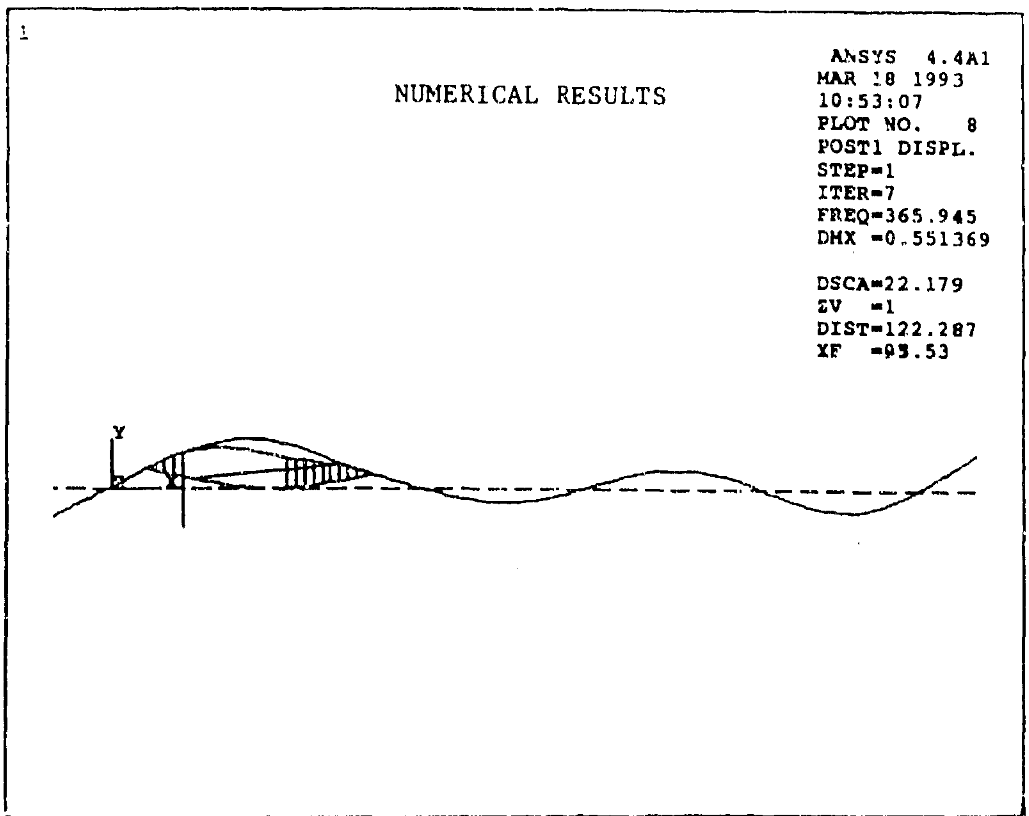
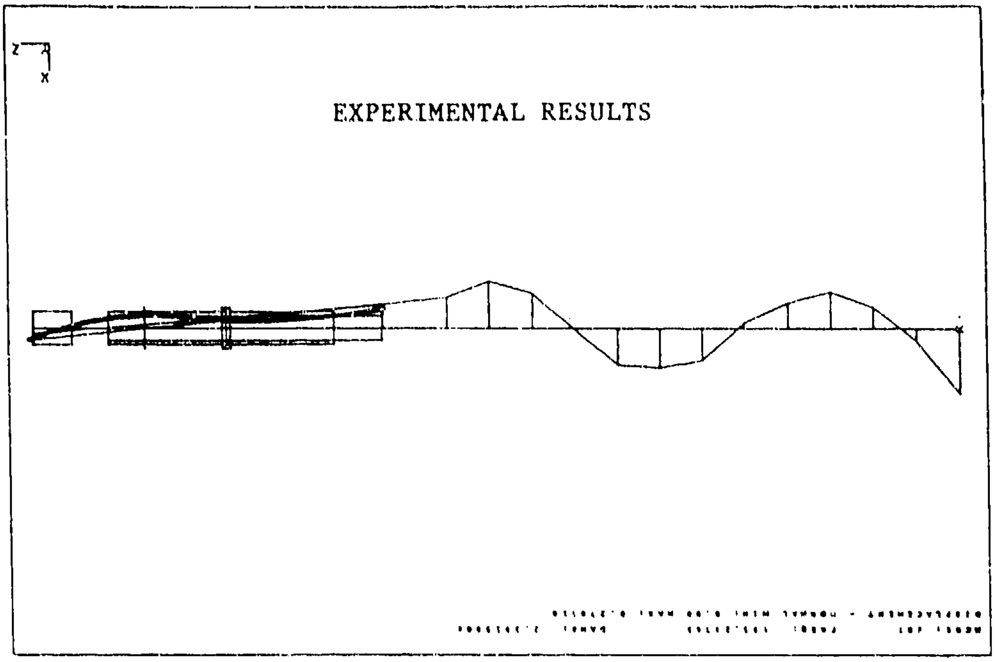


Figure 15. Comparison of numerical and experimental vertical mode shapes (fourth flexural mode ?).



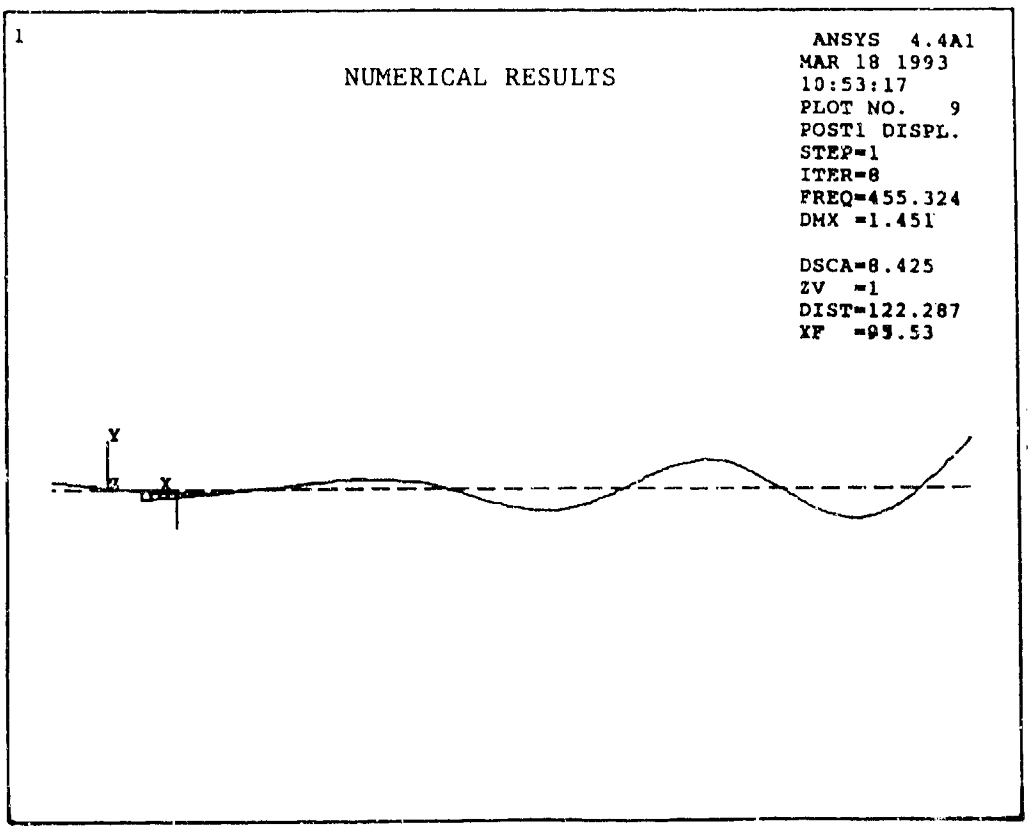


Figure 16. Comparison of numerical and experimental vertical mode shapes (fifth flexural mode ?).

speculated that the trunnions were exhibiting some resistance to rotation and a rotational spring was added at that location, which improved both predictions.

Finally, some of the parts that were not originally represented in the model need to be included. These parts include the thermal shrouds, bore sight, mantelet, and trunnion mounts. Future models will incorporate these parts and hopefully better represent the whole system.

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